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**Analysis of Vegetative on Six Different Landfill
Cover Profiles in an Arid Environment**

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Brian Dwyer, Gretchen Newman, and Gale L. Wolters**

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Abstract

A large-scale field demonstration comparing final landfill cover designs was constructed and monitored at Sandia National Laboratories in Albuquerque, New Mexico. Two conventional designs (a RCRA Subtitle 'D' Soil Cover and a RCRA Subtitle 'C' Compacted Clay Cover) were constructed side-by-side with four alternative cover test plots designed for arid environments. The demonstration was intended to evaluate the various cover designs based on their respective water balance performance, ease and reliability of construction, and cost. A portion of this project involves the characterization of vegetation establishment and growth on the landfill covers. The various prototype landfill covers were expected to have varying flux rates (Dwyer et al 2000). The landfill covers were further expected to influence vegetation establishment and growth, which may impact site erosion potential and long-term site integrity. Objectives of this phase were to quantify the types of plants occupying each site, the percentage of ground covered by these plants, the density (number of plants per unit area) of plants, and the plant biomass production. The results of this vegetation analysis are presented in this report.

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1.0 Introduction

The purpose of this report is to examine the design of landfill covers on potential revegetation of the landfill cover. The major environmental problems associated with landfills derive from production of leachate, erosion, gas generation, and intrusive vectors (e.g., plant roots and burrowing animals). Surface water can infiltrate landfill covers with the potential of leaching wastes into groundwater and erosion of the cover can breach the cap, exposing waste. Establishing a cover that can prevent some of these problems is vital to the success of the landfill and the regulatory process. Sandia National Laboratories implemented the Alternative Landfill Cover Demonstration (ALCD) project to evaluate alternative landfill cover designs in a semi-arid desert region (Dwyer, et al., 2000). The six landfill covers tested for this research were: 1) RCRA Subtitle 'D' Cover; 2) Geosynthetic Clay Layer (GCL) Cover; 3) RCRA Subtitle 'C' Cover; 4) Capillary Barrier; 5) Anisotropic Barrier; and 6) Evapotranspiration (ET) Cover. The construction of the covers was performed in two phases. Phase I began in late summer of 1995 (landfill cover 1-3) and Phase II was completed in August of 1996 (landfill cover 4-6). After construction each site was seeded with a mixture of native plants and watered to establish plant species. One of the objectives of this study was to evaluate the recovery and establishment of vegetation at the six-engineered landfills. Vegetation characteristics examined included plant cover, density, and biomass. The ALCD tested six different engineered landfill covers to monitor surface and subsurface soil moisture.

1.1 Technical Objectives

The technical objectives of this specific research within the scope of the ALCD included:

1. Impacts of the landfill cover design on revegetation;
2. Influence of irrigation on landfill cover revegetation; and
3. Influence of vegetation cover and precipitation on erosion.

The impact of landfill cover design on revegetation was quantified by evaluating individual and species percent cover, density, and biomass. Plant establishment was compared to irrigation to determine if irrigation effects the vegetation establishment of a disturbed area. Previous studies have reported that nitrogen and water are the limiting factors influencing plant establishment and growth in arid and semiarid environments. Nitrogen loading has proved to increase biomass and decrease species richness (Haddad, et al., 2000). Irrigation has been shown to have some beneficial effects on disturbed arid regions.

1.2 Study Area

Sandia National Laboratories (SNL) is located in Bernalillo County at the foot of the Manzano Mountains adjacent to Albuquerque, New Mexico. The SNL facilities are located on the Kirtland Air Force Base reservation (USAF property with co-use agreements with the Department of Energy and SNL). KAFB military reservation is located on two broad mesas bisected by the Tijeras Arroyo, an east/west canyon. These mesas are bound by the Manzano Mountains (Cibola National Forest) to the east and the Rio Grande River to the west and are known as the Rio Grande Basin area. Elevations in this area range from 1500 meters (m) at the Rio Grande River to 3255 m at the crest of the Sandia Mountains. KAFB mean elevation is 1630 m. The general study site is located 10-km southeast of Albuquerque, NM nearly midway between the Rio Grande and the crest of the Manzano Mountains. The site exists on a nearly level to slightly rolling bench at elevation of approximately 1,600 meter (m).

This general area is characterized by low precipitation, wide temperature extremes, dry gusty winds, and usually short duration torrential rains in the form of erratic precipitation. The average annual precipitation is 21 cm with the majority occurring during July through September. Winter months are typically dry with <5 cm of precipitation. Daytime temperatures range from an average of 32° C to 34° C during the summer and an average of 10° C during the winter months.

This area of the Southwest is typical of a semi-arid desert environment with many species of drought-resistant flora; consisting of grasses, shrubs, and cacti. The Rio Grande Basin semi-arid desert vegetation consists of natural southwestern rangeland species dominated by blue grama *Bouteloua gracilis* (H.B.K.) Lag. ex Steud., black grama *B. eriopoda* (Torr.) Torr, sideoats grama *B. curtipendula* (Michx.) Torr., and sand dropseed *Sporobolus cryptandrus* (Torr.) Gray with a few interspersed forbs and an occasional fourwing saltbush *Atriplex canescens* (Pursh) Nutt.

2.0 Methodology

The landfill study site consists of an area approximately 91.4 m by 135 m (300 ft x 443 ft) with the six landfill types, each measuring 12.2 m by 91.4 m (40 ft x 300 ft), superimposed on the site as illustrated in Figure 1. The study area was built in two phases. The Phase I construction was completed August 1995 and was composed of the first three southern most landfill designs. The three Phase I landfills included: 1) RCRA Subtitle 'D' Cover; 2) Geosynthetic Clay Layer (GCL) Cover; and 3) RCRA Subtitle 'C' Cover. These 3 landfills were seeded late in the summer of 1995. Phase II landfill construction was completed in August 1996. This consisted of the Capillary Barrier, Anisotropic Barrier, and Evapotranspiration (ET) Cover. Phase II landfills were seeded in the late summer of 1996. Both Phase I and Phase II sites were seeded with a similar mixture of native plants, consisting of Indian ricegrass *Oryzopsis hymenoides*, galleta

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Figure 1. Photograph and schematic of the Alternative Landfill Cover Demonstration project.

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Hilaria jamesii (Torr.) Benth., sideoats grama, blue grama, sand dropseed, and fourwing saltbush.

Each landfill plot was divided into two equal subplots (east and west subplots) measuring approximately 12.2 m by 45.7 m (40 ft x 150 ft) as illustrated in the schematic in Figure 1. Sprinklers were installed on the east sides of each landfill to allow for stress testing. At the time of seeding both sides of the landfill were watered to establish growth. On each subplot four permanently marked 20 m (65.6 ft) transects were established for use during the annual characterization of vegetation (see Figure 2). A 5 x 10 cm microplot was placed at 1-meter intervals along each transect as described by Pase (1981) to determine plant cover. Larger 50 x 100 cm plots were placed at 5, 10, and 15-m intervals along each transect to determine plant density as described by Pase (1981). Annual standing plant biomass was determined by centering a 10 x 88 m grid over each landfill type and numbering the 880-m² cells consecutively, 10 per row, starting from zero at the northeast corner and terminating with 879 in the southwest corner. Ten random numbers, five between zero and 439 and five between 440 and 879 were selected as the m² clip plots on each landfill type. The clip plots provided five estimates of standing biomass on the irrigated area and five on the non-irrigated areas of each landfill type. Clipped samples were placed in paper bags and oven dried at 60^o C for 48 hours before weighing. Figure 3 shows photographs of the plant cover, plant density and clipping grids used in the field. Plant cover and density were estimated at the end of the growing season (October 1 - November 30) annually between the years 1997 through 2000 while biomass was estimated only at the end of the 1999-2000 growing season.

The statistical analysis included the comparison of the six landfill cover plots and the east versus west vegetation recovery. Analysis of variance (ANOVA) as described by Steel and Torrie (1960) was used to make mean comparisons of eastern and western subplots of each landfill treatment and pooled treatments within phases. Landfill comparisons and phases were compared by the t-test as described by Steel and Torrie (1960). All analyses were evaluated at $\alpha = 0.05$ and 0.01.

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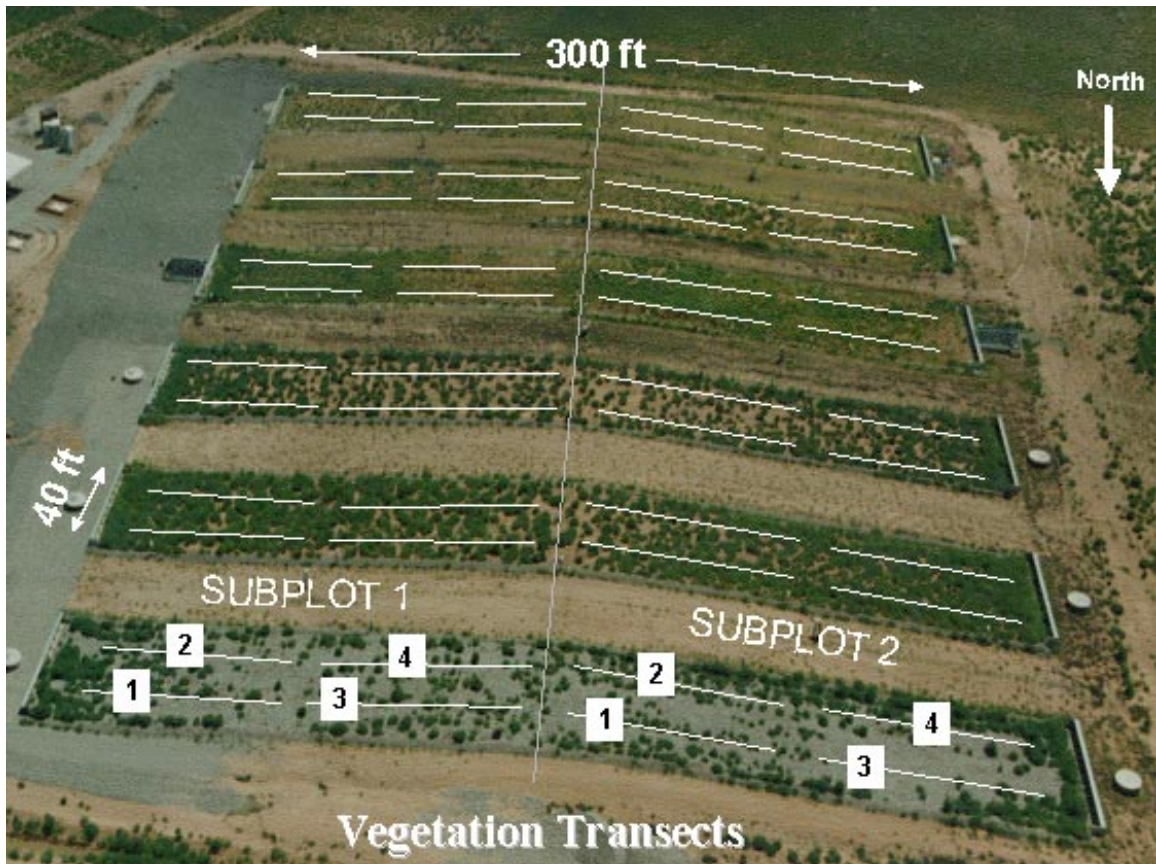


Figure 2. Schematic diagram of the vegetation transects used at the Alternative Landfill Cover Demonstration project.



Species Count



Vegetation Clipping



Density Count

Figure 3. Photographs of grids used during vegetation counts and vegetation collections.

RESULTS

There was substantial difference in plant establishment and subsequent succession between each landfill plot/treatment and the year. Phase I (first three landfills constructed) plants were quick to establishment the first year compared to Phase II plants, but all subplots percent foliar cover decreased the last two years ('99 & '00). Over the life of the project, the RCRA Subtitle C Compacted Clay Cover had the highest total plant foliar cover (total plant species), followed by the Evapotranspiration (ET) Soil Cover. The Capillary Barrier Cover had the lowest plant foliar cover for the entire sampling period (1997-2000). This can be seen in landfill photographs (Figure 4 and 5). The RCRA D Cover also had the highest concentration of Russian Thistle (*Salsola kali*) during 97 and 98, but decreased dramatically the following two years. The Anisotropic Barrier Cover exhibited an increase in Russian Thistle during the fall of 98 with 159.9 per 0.5 m² plot and decreased slowly over the next two years, 73.4 and 27.8 per 0.5-m² plots respectively. The mean percent cover and mean density is presented in Tables 1-10.

The Anisotropic Barrier Cover had the highest plant density of small herbs (number of plants per unit area) with a total of 787 per 0.5-m² plot. The RCRA Subtitle C Cover had the second highest plant density with 528 per 0.5 m² plot, which is a small component of the total biomass (see Table 11 and 12). The ET cover had the highest biomass overall (see Table 11 and 12). Plant density was significantly lower for the Capillary Barrier Cover (136 per 0.5 m² plot) than the other six treatment plots. The plant percent cover, density, and biomass totals are presented in Tables 1-12; averages for each plot are presented in Appendix A.

There were significant differences in foliar coverage and density between the Phase I/II east and west subplots across the life of the project. Phase II landfill treatment plants were slow to establish but improved over the life of the project. Of the three Phase II landfills, ET landfill cover improved the most over the five years. Edge and gradient effects were observed on all landfill plots. Detailed descriptions of the data percent cover, density, and biomass are presented below.

There was a significant difference between the total vegetation on the east and west treatments ($p = 0.054$) and between the landfill type subplots ($p = 0.0013$). In general, all landfill cover east treatment plots had a greater percent cover, density, and biomass than the west plots.

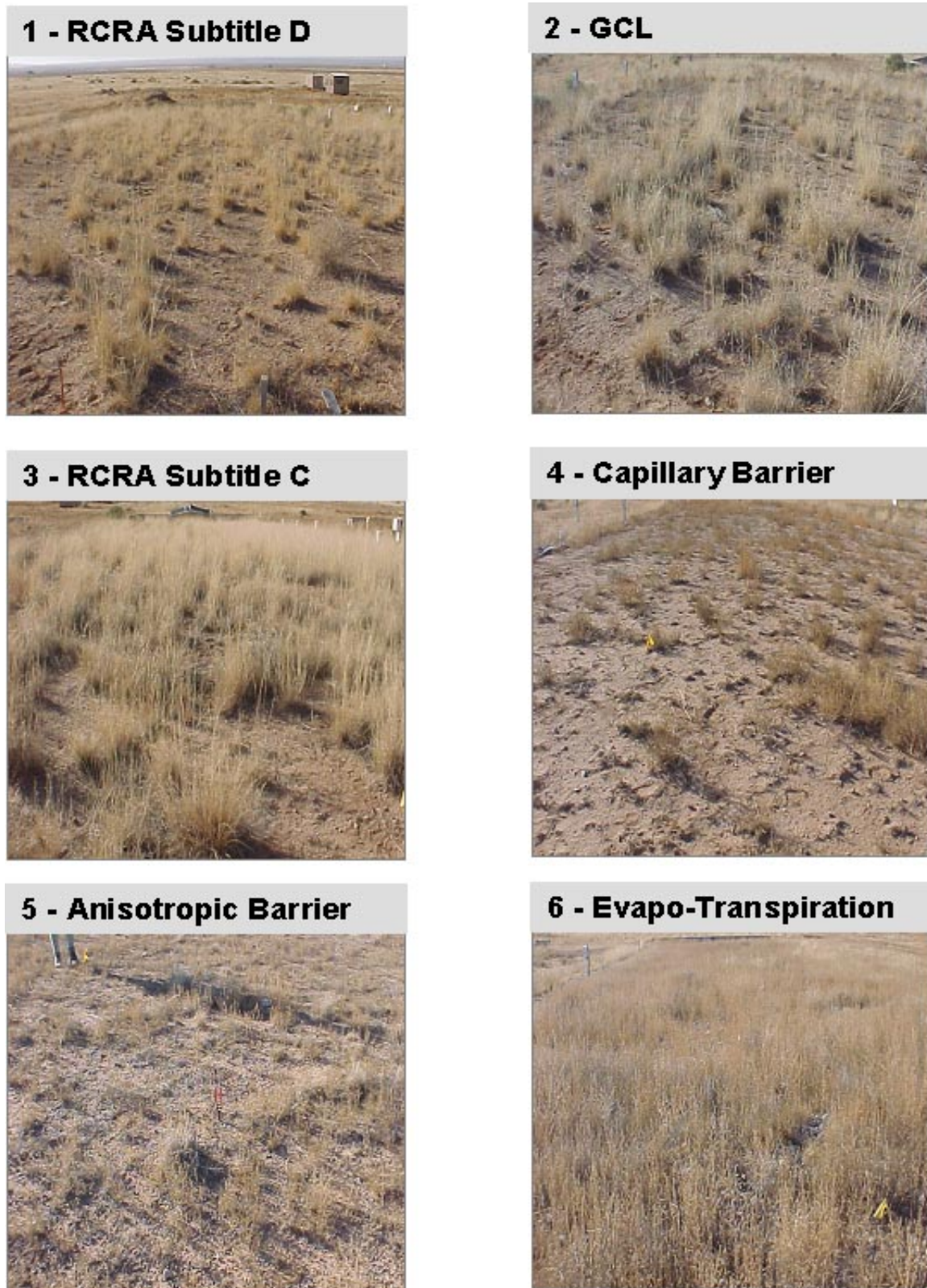


Figure 4. Photographs of vegetative cover on each landfill cover design (photos taken November 1999).

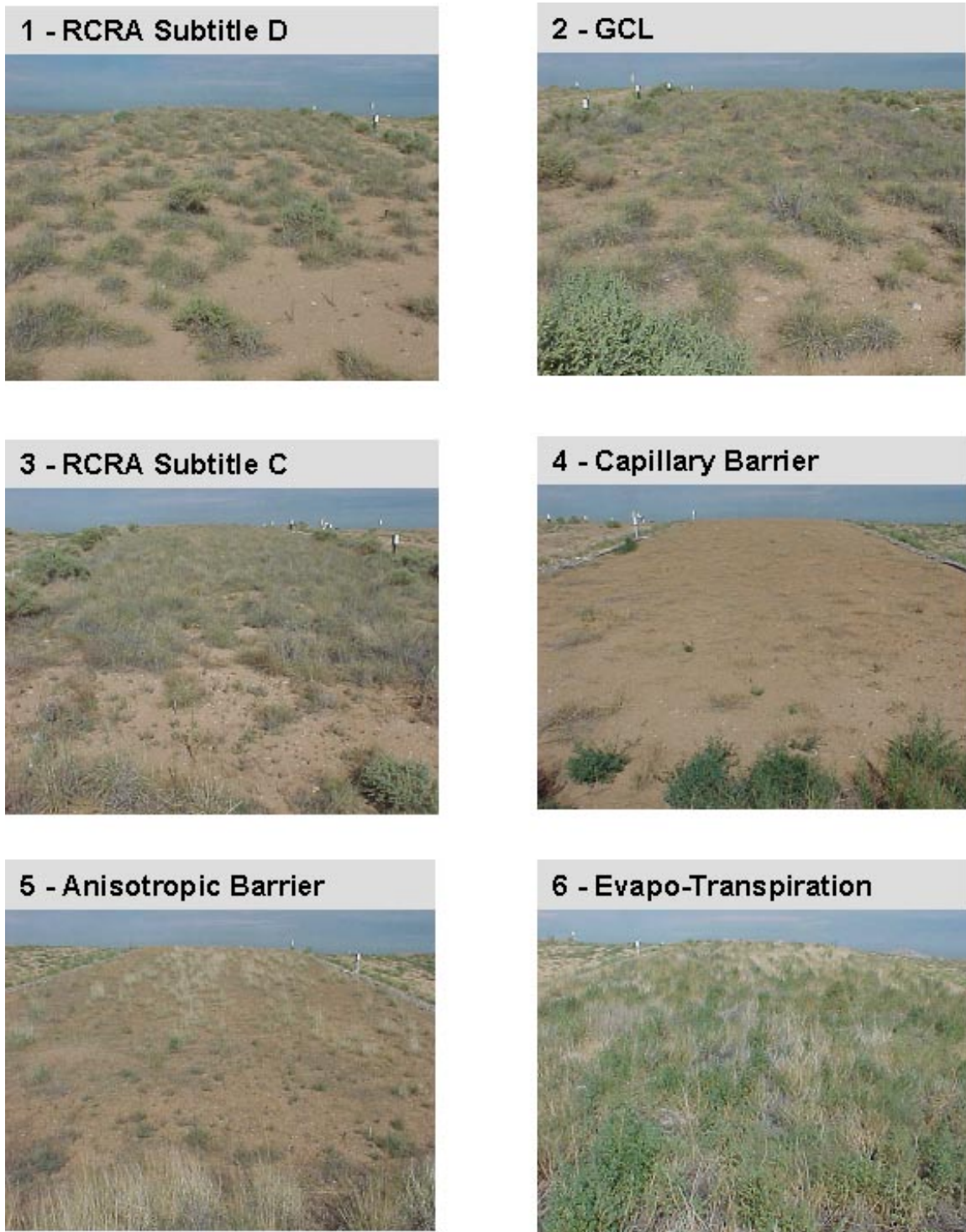


Figure 5. Photographs of vegetative cover on each landfill cover design (photos taken July 2001).

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Three-awn
Aristida



Blue Grama Grass
gracilis



Macaranthea Rosette
canescens



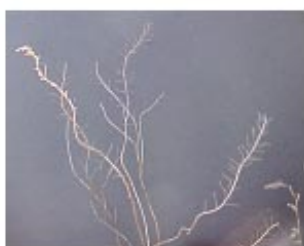
Summer Cypress
Kochia scoparia



Indian Rice Grass
Oryzopsis hymenoides



Macaranthea
canescens



Pepperweed
Lepidium



Indian Rice Grass
Oryzopsis hymenoides



Galleta Grass
Hilaria jamesii



Crested Wheat Grass
cristatum



Broom Snake Weed
Gutierrezia sarothrae



Four-Wing Saltbrush
Atriplex

Figure 6. Vegetation types found on the Landfill Cover Plots.

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Fall 1997

Plant Cover. During the summer and fall of 1997, precipitation significantly enhanced grass and total plant cover on all Phase I landfill treatments in the fall of 1997. The mean percent grass cover averaged nearly 13% for the east plot versus 4% on the west plots on Phase I landfill covers (Table 1). Total plant cover averaged nearly 18% on east plots but only about 9% on the western portions of the landfill covers. East plots were pooled to test among treatment effects by phase. Phase I landfill treatments showed RCRA Subtitle 'C' generally had greater grass, forbs, and total plant cover than either the GCL or RCRA Subtitle 'D' treatments.

The opposite effect was observed on Phase II sites. Phase II sites were completed in 1996 which was a relatively dry year for precipitation and has since been followed by dry years. Western portions of the Phase II landfills averaged only 0.17% cover but significantly more than on the eastern portions. Weed, forbs and shrub cover varied widely on both Phase I and Phase II sites and exhibited no consistent trend. No landfill cover differences were detected on Phase II treatments.

Plant Density. During fall 1997, grass density exhibited the same general trend in response to precipitation as plant cover. Grass density was greater on all Phase I east plots versus the western plots by averaging over twice as many plants per 0.5 m² area. Eastern plots averaged 14.5 while the western plots averaged 7.1 (Table 2). Weed, forbs, and total plant density displayed a similar but less consistent trend as grass density on Phase I sites. RCRA Subtitle 'D' had the greatest total plant density primarily due to the thick stand of annual weeds. Plant density on RCRA Subtitle C, although similar to RCRA Subtitle 'D' plant density, consisted of a more uniform mix of grasses, weeds, and forbs.

Plant density was substantially greater on Phase I treatments than on Phase II treatments. On Phase II treatments, only weeds illustrated a consistent trend of more plants per unit area. West plots and east plots yielded 1.8 and 0.9 plants per 0.5 m², respectively, substantially less than on Phase I sites. Western Phase II plots, on the average, supported more grass, weeds, and total plant density than eastern plots, but Phase II plant density was generally less than 10% of that on Phase I sites.

Spring 1998

Plant Cover. In the spring of 1998, grass cover was enhanced by precipitation on both east and west plots on all Phase I treatments with cover ranging from 19.81% to 42.81% on the eastern sides compared to 6.19% to 8.75% on the western portions of the landfill covers (Table 3). Weed cover was generally greater on the west subplots than on east sites on all treatments except RCRA Subtitle D. Across all Phase I sites, grass, forbs, and total plant cover was greater on eastern plots compared to western plots. Only total plant cover was influenced by landfill treatment in Phase I. GCL and RCRA Subtitle 'C' sites had greater total plant cover than RCRA Subtitle D, with grass and weeds providing the predominant amount of cover on all treatments.

No consistent trends due to precipitation were observed on Phase II sites. Weeds provided the majority of cover on all Phase II landfills. In areas where differences in total plant cover were detected, the differences were due to weed cover. Among landfill

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Table 1. The mean percent vegetation cover by categories and total percent cover for landfill plots collected fall of 1997.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
Phase I					
----- percent cover -----					
RCRA Subtitle D					
East Subplot	8.38a ¹	3.00	0.06b	0.00	11.44a
West Subplot	3.68b	3.69	0.25a	0.00	7.62b
<i>Mean</i>	<i>6.03b²</i>	<i>3.34</i>	<i>0.16b</i>	<i>0.00</i>	<i>9.53b</i>
GCL					
East Subplot	10.31a	3.38	0.56	1.13a	15.38a
West Subplot	0.63b	2.69	1.13	0.00b	4.45b
<i>Mean</i>	<i>5.47b</i>	<i>3.03</i>	<i>0.84ab</i>	<i>0.56</i>	<i>9.90b</i>
RCRA Subtitle C					
East Subplot	20.00a	2.19b	3.93a	0.38a	26.50a
West Subplot	7.19b	6.69a	1.13b	0.00b	15.01b
<i>Mean</i>	<i>13.59a</i>	<i>4.44</i>	<i>2.53a</i>	<i>0.19</i>	<i>20.75a</i>
<i>Mean East Subplot</i>	<i>12.89a</i>	<i>2.85b</i>	<i>1.52</i>	<i>0.50a</i>	<i>17.76a</i>
<i>Mean West Subplot</i>	<i>3.83b</i>	<i>4.35a</i>	<i>0.83</i>	<i>0.00b</i>	<i>9.01b</i>
Phase II					
Capillary Barrier					
East Subplot	0.00b	0.06a	0.00	0.00	0.06
West Subplot	0.06a	0.00b	0.00	0.00	0.06
<i>Mean</i>	<i>0.03</i>	<i>0.03</i>	<i>0.00</i>	<i>0.00</i>	<i>0.06</i>
Anisotropic Barrier					
East Subplot	0.00b	0.00	0.31a	0.00	0.31
West Subplot	0.19a	0.00	0.00b	0.00	0.19
<i>Mean</i>	<i>0.09</i>	<i>0.00</i>	<i>0.16</i>	<i>0.00</i>	<i>0.25</i>
ET Cover					
East Subplot	0.00b	0.06b	0.19a	0.00	0.25b
West Subplot	0.25a	1.75a	0.00b	0.00	2.00a
<i>Mean</i>	<i>0.13</i>	<i>0.91</i>	<i>0.09</i>	<i>0.00</i>	<i>1.13</i>
<i>Mean East Subplot</i>	<i>0.00b</i>	<i>0.04b</i>	<i>0.16a</i>	<i>0.00</i>	<i>0.20b</i>
<i>Mean West Subplot</i>	<i>0.17a</i>	<i>0.58a</i>	<i>0.00b</i>	<i>0.00</i>	<i>0.75a</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 2. The mean species density and total plant density for landfill plot/treatments collected fall of 1997.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
----- plant density per 50 x 100 cm plot -----					
Phase I					
RCRA Subtitle D					
East Subplot	8.9a ¹	81.4	0.2	0.0	90.5
West Subplot	3.9b	76.5	0.3	0.0	80.7
<i>Mean</i>	<i>6.4b²</i>	<i>79.9a</i>	<i>0.3b</i>	<i>0.0</i>	<i>85.6a</i>
GCL					
East Subplot	13.6a	44.6a	1.1a	0.1	59.4a
West Subplot	3.9b	23.7b	0.5b	0.1	28.2b
<i>Mean</i>	<i>8.7b</i>	<i>34.1b</i>	<i>0.8ab</i>	<i>0.1</i>	<i>43.7b</i>
RCRA Subtitle C					
East Subplot	21.1a	39.9	2.2a	0.1a	63.3a
West Subplot	13.6b	36.3	0.5b	0.0b	50.4b
<i>Mean</i>	<i>17.3a</i>	<i>38.1b</i>	<i>1.3a</i>	<i>0.0</i>	<i>56.7ab</i>
<i>Mean East Subplot</i>	<i>14.5a</i>	<i>55.3a</i>	<i>1.2a</i>	<i>0.0</i>	<i>71.0a</i>
<i>Mean West Subplot</i>	<i>7.1b</i>	<i>45.5b</i>	<i>0.4b</i>	<i>0.0</i>	<i>53.1b</i>
Phase II					
Capillary Barrier					
East Subplot	1.3a	0.9b	0.1a	0.0	2.3b
West Subplot	5.1b	1.5a	0.0b	0.0	6.6a
<i>Mean</i>	<i>3.2</i>	<i>1.2</i>	<i>0.1b</i>	<i>0.0</i>	<i>4.5</i>
Anisotropic Barrier					
East Subplot	3.8	0.9b	0.1	0.0	4.8
West Subplot	3.8	2.4a	0.1	0.0	6.3
<i>Mean</i>	<i>3.8</i>	<i>1.6</i>	<i>0.1b</i>	<i>0.0</i>	<i>5.5</i>
ET Cover					
East Subplot	2.8	0.8b	1.0a	0.0	4.6
West Subplot	2.0	1.6a	0.1b	0.0	3.7
<i>Mean</i>	<i>2.4</i>	<i>1.2</i>	<i>0.6a</i>	<i>0.0</i>	<i>4.2</i>
<i>Mean East Subplot</i>	<i>2.6b</i>	<i>0.9b</i>	<i>0.4a</i>	<i>0.0</i>	<i>3.9b</i>
<i>Mean West Subplot</i>	<i>3.7a</i>	<i>1.8a</i>	<i>0.1b</i>	<i>0.0</i>	<i>5.6a</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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treatments, Anisotropic Barrier had greater weed and total plant cover than either Capillary Barrier or ET Cover treatment, but again the differences were due primarily to the high proportion of weedy cover.

Plant Density. In the spring of 1998 grass, weed, forbs, shrub, and total plant density was greater on GCL and within all landfill treatments on the east portions of landfills as opposed to the western portions. However, grass and forbs densities were greater on all Phase I east plots than on western plots. Weeds were the dominant vegetation within all Phase I landfill treatments. Weed density ranged from 28.7 to 32.9 plants per 0.5 m² (Table 4). Among Phase I landfill treatments, grass density was greatest on RCRA Subtitle 'C' while weeds were in greater density on RCRA Subtitle D, although not substantially greater than on GCL.

Plant density was considerably lower on all Phase II sites than on Phase I sites. Weed and total plant density were generally greater on the western portions than on eastern portions of landfill covers while forbs density, although low, was greater on the eastern plots. Anisotropic Barrier and ET Cover landfill treatments had similar but greater total plant density than the Capillary Barrier. The Anisotropic Barrier and ET Cover plant densities were 8.8 to 9.4 plants respectively, compared to 4.8 plants per 0.5 m², on the Capillary Barrier treatment. Grasses and forbs were the predominant vegetation types on ET Cover while weeds predominated on the Anisotropic Barrier treatment.

Fall 1998

Plant Cover. When vegetation was sampled in fall 1998, grasses were the predominant cover type on Phase I eastern plots while weeds predominated the western portions of landfill covers. Within treatments, grass cover averaged 37% on east plots compared to about 16% on Phase I western plots while weed cover averaged 14% and about 4% on east versus west sides of landfill covers (Table 5). Within Phase I landfill treatments, forbs were the only vegetation type to respond to landfill treatment and they were a very minor component of total plant cover.

Weed cover on Phase II landfill covers was greatest on the western plot of the Anisotropic Barrier landfill cover. Within landfill treatments, eastern plots showed greater grass, forbs, and total plant cover. Plant cover responses to precipitation were variable among landfill types. Grass and forbs cover was greatest on the Anisotropic Barrier but weed and total plant cover was by far greater on ET Cover.

Plant Density. In the fall of 1998, eastern plots showed enhanced grass density and the western plots showed increased weed and total plant density on all Phase I landfill treatments. Forbs and shrubs responded inconsistently to precipitation. Within landfill treatments, grass density averaged nearly two times greater on eastern plots (9.3 versus 5.6 plants per 0.5 m²), forbs were three times greater and shrubs two times greater on all Phase I eastern plots (Table 6). However, weeds were over 15 times greater on Phase I western plots while weeds strongly influenced the total plant density. Grass was the only vegetative type that responded to precipitation among landfill treatments. Grass

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density averaged 10.5 plants per unit area on RCRA Subtitle 'C', but only about 5 per unit area on RCRA Subtitle 'D' and GCL landfill treatments.

On Phase II sites, plant density response was variable and inconsistent to first growing season precipitation. On the landfill types that did show a response in the fall of 1998, western plots generally had the greatest density for all classes of vegetation. Among landfill treatments, Anisotropic Barrier supported the greatest grass, weed, forbs, and total plant density. Total plant density averaged 139, 63, and 28 plants per 0.5 m² on Anisotropic Barrier, ET Cover, and Capillary Barrier, respectively.

Fall 1999

Plant Cover: Periodic precipitation during the first growing season influenced plant basal cover only on the GCL landfill (Table 7). Grass cover (5.74%) and total plant cover (6.77%) was substantially greater on the eastern GCL landfill plot compared to the western portion (1.97 and 3.97% respectively). Forbs, provided more cover on the western than eastern portions of GCL landfill. Eastern portions of landfill covers contained approximately 7.79% grass and 8.66% total plant cover compared to western portions of Phase I landfills, which had 3.97% and 5.25% respectively. Within treatments, weed cover on Phase I sites, was greater on the western portions (0.79%) than on eastern portions (0.18 %). Among landfill treatments, the only difference observed was in forbs cover, which was greater on the GCL landfill (0.45%) than either the RCRA Subtitle 'D' or RCRA Subtitle 'C' landfills (0.03% and 0.08% respectively).

Perennial grass was the dominate vegetation type on Phase I landfills providing approximately 85% of the relative plant cover. Weeds, shrubs, and forbs produced only 7%, 6%, and 2% of the relative cover, respectively.

There was a significant landfill treatment influence on weed and total plant cover for pooled Phase II landfill treatments. ET Cover had significantly more weed (10.97%) and total plant cover (12.71%) than either of the other Phase II landfill treatments. Capillary barrier treatment had the least weed (3.30%) and the least total plant cover percentage (3.38%) of all Phase II landfill treatments.

Annual weeds were the dominant vegetation cover type on Phase II landfills producing approximately 88% of the relative cover. Grasses provided approximately 11% of the relative plant cover and forbs only provided about 1% of the relative plant cover. Woody shrubs were not detected on Phase II landfill treatments at the end of the 1999 growing season.

Plant Density. When Phase I treatments were pooled, the western subplots supported a more dense stand of annual weeds than the eastern subplots (10.2 versus 1.3 plants per 0.5 m², respectively) (Table 8). Total plant density was also greater on non-irrigated than the east subplots sites due to the thick stand of weeds. Perennial grass density was influenced by Phase I landfill treatments with the greatest grass density on RCRA Subtitle 'C' site (7.5 per 0.5 m²), least grass density on GCL site (3.7 plants per 0.5 m²), and intermediate density on RCRA Subtitle 'D' site (4.8 plants per 0.5 m²).

Relative plant density was evenly shared by predominately perennial grasses and annual weeds with 44% with 47% respectively, on Phase I landfill treatments. Relative density of perennial forbs and woody shrubs was 7 and 2 %, respectively on Phase I

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Table 3. The mean percent vegetation cover by categories and total percent cover for landfill plots collected spring of 1998.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
	----- percent cover -----				
Phase I					
RCRA Subtitle D					
East Subplot	19.81a ¹	15.56	0.19	0.00	35.56a
West Subplot	6.19b	21.00	0.19	0.00	7.38b
Mean	13.00	18.28	0.19	0.00	31.47b ²
GCL					
East Subplot	28.94a	18.13b	1.00a	0.00	48.07
West Subplot	8.31b	39.88a	0.00b	0.00	48.19
Mean	18.63	29.00	0.50	0.00	48.13a
RCRA Subtitle C					
East Subplot	42.81a	17.69b	0.00	0.00	60.50a
West Subplot	8.75b	34.56a	0.00	0.00	43.31b
Mean	25.78	26.13	0.00	0.00	51.91a
Mean East Subplot	30.52a	17.13b	0.39a	0.00	48.04a
Mean West Subplot	7.75b	31.81a	0.06b	0.00	39.62b
Phase II					
Capillary Barrier					
East Subplot	0.94a	23.69b	0.00b	0.00	24.63b
West Subplot	0.06b	32.56a	0.31a	0.00	32.93a
Mean	0.50	28.13b	0.15ab	0.00	28.78b
Anisotropic Barrier					
East Subplot	3.50	51.75	0.00	0.00	55.25a
West Subplot	1.69	47.31	0.00	0.00	49.00b
Mean	2.59	49.53a	0.00b	0.00	52.12a
ET Cover					
East Subplot	1.13b	30.13	1.25	0.00	32.51
West Subplot	2.25a	30.69	0.75	0.00	33.69
Mean	1.69	30.41b	1.00a	0.00	33.10b
Mean East Subplot	1.95	35.19	0.42	0.00	37.46
Mean West Subplot	0.33	36.85	0.35	0.00	38.54

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 4. The mean species density and total plant density for landfill plot/treatments collected spring of 1998.

Landfill Plot/Treatment	Vegetation Type				total
	grass	weed	forbs	shrub	
----- plant density per 50 x 100 cm plot -----					
Phase I					
RCRA Subtitle D					
East Subplot	9.6a ¹	45.0	0.1a	0.0	54.7
West Subplot	5.4b	38.3	0.0b	0.0	43.7
Mean	7.5b ²	41.7a	0.1	0.0	49.3
GCL					
East Subplot	10.9a	31.1a	0.3a	0.2a	42.5a
West Subplot	3.4b	21.6b	0.0b	0.0b	25.0b
Mean	7.1b	26.3ab	0.2	0.1	33.7
RCRA Subtitle C					
East Subplot	14.9a	22.6	0.2a	0.1a	37.8
West Subplot	11.7b	26.2	0.0b	0.0b	37.9
Mean	13.3a	24.4b	0.1	0.1	37.9
Mean East Subplot	11.8a	32.9	0.2a	0.1a	45.0a
Mean West Subplot	6.8b	28.7	0.0b	0.0b	35.5b
Phase II					
Capillary Barrier					
East Subplot	1.5b	2.9	0.1	0.1a	4.6
West Subplot	2.1a	2.8	0.1	0.0b	5.0
Mean	1.8b	2.8b	0.1ab	0.1	4.8b
Anisotropic Barrier					
East Subplot	4.7a	4.3b	0.0b	0.0	9.0
West Subplot	1.9b	6.7a	0.1a	0.0	8.7
Mean	3.3b	5.5a	0.0b	0.0	8.8a
ET Cover					
East Subplot	5.7b	1.6b	0.5a	0.0	7.8b
West Subplot	8.1a	2.9a	0.1b	0.0	11.1a
Mean	6.9a	2.2b	0.3a	0.0	9.4a
Mean East Subplot	4.0	2.9b	0.2a	0.0	7.1b
Mean West Subplot	4.0	4.1a	0.1b	0.0	8.2a

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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landfill treatments. On Phase II landfill treatments, the eastern subplots increased the density of perennial grass only on the Anisotropic Barrier landfill with 3.4 plants per 0.5 m² compared to only 0.2 plants per 0.5 m² on the western subplots.

Phase II landfill treatments significantly influenced plant density. For example, ET Cover treatment had more weeds, forbs, and total plants per unit area than Capillary Barrier landfill. Weed and total plant density was similar on ET Cover and Anisotropic landfill treatments.

Annual weeds were by far the most abundant plant form on Phase II landfills. Relative density of annual weeds was 95%; perennial grasses contributed 3% and forbs 2%. Woody shrubs were not detected on Phase II landfill sites.

Biomass: Plant biomass on the Phase I GCL landfill east subplots was 228.3 gms/m², compared to 91.3 gms/m² on the west subplots (Table 9). The plant biomass on other Phase I landfill covers was similar.

Biomass on the Phase II east subplots landfill treatments were inconsistent. Also, biomass was inconsistent between the east and west subplots on Phase II landfill covers. The Capillary Barrier east subplot biomass was less than the west subplots of the Anisotropic Barrier and ET Cover landfills. Among Phase II landfills, biomass was greatest on the ET Cover treatment with 192.6 gms/m² but biomass was equal and substantially less on the Capillary Barrier and Anisotropic Barrier landfill treatments with about 63 gms/m².

Photographs were taken in fall 1999 of each landfill cover (Figure 4 and 5). Various vegetation types that were noted throughout the project on the different landfill covers are shown in Figure 6.

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Plant Cover: Generally, Phase I plots had significantly more grass cover than other vegetation types (7.58% grass; 1.31% weeds; 2.67% forbs; and 0.79 shrubs) while Phase II plots had generally more weeds (5.65% grasses; 14.69% weeds; 1.70 forbs; 0.05% shrubs). The Phase I East subplots had slightly higher grass coverage than the West subplots; while the West plot had significantly higher weed coverage (see Table 9). Phase II East subplots had similar shrub, forbs, and grass cover ranging from 0.79 to 2.67%; while weeds showed a significant difference between the two subplots (14.69 and 1.31).

Plant Density: The grass, weed, forbs, shrub, and total plant density was greater on the GCL, with a general trend of higher plant density on the eastern than the western subplots. Overall grass density ((15.42/0.5 m² plot) was higher on Phase I eastern subplots, with the RCRA-C subplot having the highest grass density. Among Phase I landfill subplots, grass density was greatest on the RCRA-C east subplot (see Table 10), while the west subplot had the highest forbs concentration (127/0.5 m² plot). Phase II eastern and western subplots had a higher density of weeds than the any Phase I subplots.

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Weed density ranged from 0.25 to 3.42 on Phase I plots and 4.92 to 27.25 per 0.5 m² plot. Annual weeds were by far the most abundant plant form on Phase II landfills.

During the past three years there was a significant difference between the total density of Phase I and Phase II plants. This is basically due to the increase number of forbs on both Phase I and Phase II subplots. Among landfill subplots, the Anisotropic Barrier had the greatest density for all classes of vegetation and total plant density. Total plant density averaged 21, 172, and 27 plants per 0.5 m² plot on Capillary Barrier, anisotropic Barrier, and ET cover, respectively. Woody shrubs were not detected on Phase II landfill sites.

Biomass:

The ET cover had the highest biomass with 280 gms/m² on the eastern and 159 gms/m² on the western subplots (see Table 12). The GCL landfill eastern subplots (181 gms/m² plot) had the highest biomass for the Phase I landfills. The western subplot of the Capillary Barrier had the lowest biomass with only 5-gms/m² plot. Average plant biomass on Phase I landfills was 106 gms/m². Total biomass was higher on the ET cover than all other subplots. The mean biomass between Phase I and Phase II was not significantly different 106 and 114 gms/m² , respectively.

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Table 5. The mean percent vegetation cover by categories and total percent cover for landfill plots collected fall of 1998.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
	----- percent cover -----				
Phase I					
RCRA Subtitle D					
East Subplot	29.81a ¹	5.38b	0.01a	1.25b	36.45
West Subplot	13.38b	12.95a	0.00b	4.75a	31.08
Mean	21.59	9.16	0.00b ²	3.00	33.75
GCL					
East Subplot	32.25a	2.13b	1.75	0.31a	36.44a
West Subplot	11.69b	21.00a	1.25	0.06b	34.00b
Mean	23.47	11.56	1.50a	0.19	36.72
RCRA Subtitle C					
East Subplot	46.31a	3.19b	0.75	1.58	51.83a
West Subplot	22.75b	8.06a	0.50	1.25	32.56b
Mean	34.53	5.63	0.63b	1.41	42.20
Mean East Subplot	37.13a	3.56b	0.84	1.05	42.58a
Mean West Subplot	15.94b	14.00a	0.58	2.02	32.54b
Phase II					
Capillary Barrier					
East Subplot	0.00	23.35a	0.19a	0.00	22.51a
West Subplot	0.00	16.25b	0.00b	0.00	16.25b
Mean	0.01b	19.30c	0.09b	0.00	19.38c
Anisotropic Barrier					
East Subplot	6.69a	29.06b	2.94a	0.00	38.69
West Subplot	1.56b	37.13a	0.75b	0.00	39.44
Mean	4.13a	33.09b	1.84a	0.00	39.07b
ET Cover					
East Subplot	2.69a	66.13a	0.09	0.00	68.91a
West Subplot	0.94b	54.75b	0.00	0.00	55.69b
Mean	1.81ab	60.44a	0.06b	0.00	62.31a
Mean East Subplot	3.13a	39.18	1.08a	0.00	43.39a
Mean West Subplot	0.83b	36.04	0.25b	0.00	37.12b

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 6. The mean species density and total plant density for landfill plot/treatments collected fall of 1998.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
----- plant density per 50 x 100 cm plot -----					
Phase I					
RCRA Subtitle D					
East Subplot	6.6a ¹	12.8b	0.9	0.0b	20.3b
West Subplot	4.8b	72.4a	0.6	0.1a	77.9a
<i>Mean</i>	<i>5.7b²</i>	<i>42.6</i>	<i>0.7</i>	<i>0.1</i>	<i>49.1</i>
GCL					
East Subplot	8.6a	0.1b	3.9a	0.2a	12.8b
West Subplot	3.7b	76.4a	0.9b	0.1b	81.1a
<i>Mean</i>	<i>6.1b</i>	<i>38.2</i>	<i>2.4</i>	<i>0.1</i>	<i>46.8</i>
RCRA Subtitle C					
East Subplot	12.6a	0.1b	2.6a	0.5a	15.8b
West Subplot	8.5b	65.4a	0.6b	0.1b	74.6a
<i>Mean</i>	<i>10.5a</i>	<i>32.8</i>	<i>1.6</i>	<i>0.3</i>	<i>45.2</i>
<i>Mean East Subplot</i>	<i>9.3a</i>	<i>4.3b</i>	<i>2.4a</i>	<i>0.2a</i>	<i>16.2b</i>
<i>Mean West Subplot</i>	<i>5.6b</i>	<i>71.4a</i>	<i>0.7b</i>	<i>0.1b</i>	<i>77.8a</i>
Phase II					
Capillary Barrier					
East Subplot	0.1b	24.9	0.1b	0.0	25.1
West Subplot	0.4a	30.7	0.2a	0.0	31.3
<i>Mean</i>	<i>0.3b</i>	<i>27.8c</i>	<i>0.1b</i>	<i>0.0</i>	<i>28.2b</i>
Anisotropic Barrier					
East Subplot	2.3	123.1b	1.7a	0.0	127.1b
West Subplot	1.7	149.9a	0.2b	0.0	151.8a
<i>Mean</i>	<i>2.0a</i>	<i>136.5a</i>	<i>0.9a</i>	<i>0.0</i>	<i>139.4a</i>
ET Cover					
East Subplot	1.7	56.8	0.1b	0.0	58.6
West Subplot	1.1	66.4	0.3a	0.0	67.8
<i>Mean</i>	<i>1.4a</i>	<i>61.6b</i>	<i>0.2b</i>	<i>0.0</i>	<i>63.2b</i>
<i>Mean East Subplot</i>	<i>1.4</i>	<i>68.3</i>	<i>0.6a</i>	<i>0.0</i>	<i>70.3</i>
<i>Mean West Subplot</i>	<i>1.1</i>	<i>82.3</i>	<i>0.2b</i>	<i>0.0</i>	<i>83.6</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 7. The mean percent vegetation cover by categories and total percent cover for landfill plots collected fall of 1999.

Landfill Plots/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
----- percent cover -----					
Phase I					
RCRA Subtitle D					
East Subplot	8.72	0.13	0.03	0.66	9.54
West Subplot	3.38	0.59	0.03	0.53	4.53
<i>Mean</i>	<i>6.05</i>	<i>0.36</i>	<i>0.03b²</i>	<i>0.59</i>	<i>7.03</i>
GCL					
East Subplot	5.74a ¹	0.09	0.19b	0.75	6.77a
West Subplot	1.97b	1.15	0.72a	0.13	3.97b
<i>Mean</i>	<i>3.85</i>	<i>0.62</i>	<i>0.45a</i>	<i>0.44</i>	<i>5.36</i>
RCRA Subtitle C					
East Subplot	8.91	0.28	0.09	0.38	9.66
West Subplot	6.56	0.63	0.06	0.00	7.25
<i>Mean</i>	<i>7.74</i>	<i>0.45</i>	<i>0.08b</i>	<i>0.19</i>	<i>8.46</i>
<i>Mean East Subplot</i>	<i>7.79a</i>	<i>0.18b</i>	<i>0.10</i>	<i>0.59</i>	<i>8.66a</i>
<i>Mean West Subplot</i>	<i>3.97b</i>	<i>0.79a</i>	<i>0.27</i>	<i>0.22</i>	<i>5.25b</i>
Phase II					
Capillary Barrier					
East Subplot	0.03	2.59	0.13	0.00	2.75
West Subplot	0.00	4.00	0.00	0.00	4.00
<i>Mean</i>	<i>0.02</i>	<i>3.30c</i>	<i>0.06</i>	<i>0.00</i>	<i>3.38c</i>
Anisotropic Barrier					
East Subplot	1.62	5.74	0.03	0.00	7.39
West Subplot	0.06	5.94	0.31	0.00	6.31
<i>Mean</i>	<i>0.84</i>	<i>5.84b</i>	<i>0.17</i>	<i>0.00</i>	<i>6.85b</i>
ET Cover					
East Subplot	0.66	11.63	0.09	0.00	12.38
West Subplot	2.56	10.31	0.16	0.00	13.03
<i>Mean</i>	<i>1.61</i>	<i>10.97a</i>	<i>0.13</i>	<i>0.00</i>	<i>12.71a</i>
<i>Mean East Subplot</i>	<i>0.77</i>	<i>6.65</i>	<i>0.08</i>	<i>0.00</i>	<i>7.50</i>
<i>Mean West Subplot</i>	<i>0.87</i>	<i>6.75</i>	<i>0.16</i>	<i>0.00</i>	<i>7.78</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 8. The mean species density and total plant density for landfill plot/treatments collected fall of 1999.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
----- plant density per 50 x 100 cm plot -----					
Phase I					
RCRA Subtitle D					
East Subplot	6.0	0.0	0.0	0.2	6.2
West Subplot	3.7	9.9	0.1	0.3	14.0
<i>Mean</i>	<i>4.7ab²</i>	<i>5.0</i>	<i>0.0</i>	<i>0.2</i>	<i>10.0</i>
GCL					
East Subplot	5.2	2.5	1.6	0.3	9.6
West Subplot	2.2	12.2	1.0	0.0	15.4
<i>Mean</i>	<i>3.7b</i>	<i>7.3</i>	<i>1.3</i>	<i>0.2</i>	<i>12.5</i>
RCRA Subtitle C					
East Subplot	7.1	1.4	1.0	0.4	9.9
West Subplot	7.8	8.6	1.7	0.1	18.2
<i>Mean</i>	<i>7.5a</i>	<i>5.0</i>	<i>1.3</i>	<i>0.3</i>	<i>14.1</i>
<i>Mean East Subplot</i>	<i>6.1</i>	<i>1.3b¹</i>	<i>0.8</i>	<i>0.3</i>	<i>8.5b</i>
<i>Mean West Subplot</i>	<i>4.6</i>	<i>10.2a</i>	<i>0.9</i>	<i>0.1</i>	<i>15.8a</i>
Phase II					
Capillary Barrier					
East Subplot	0.3	9.0	0.1	0.0	9.4
West Subplot	0.0	9.7	0.0	0.0	9.7
<i>Mean</i>	<i>0.2</i>	<i>9.3b</i>	<i>0.0b</i>	<i>0.0</i>	<i>9.5b</i>
Anisotropic Barrier					
East Subplot	3.4a	54.7	1.4	0.0	59.5
West Subplot	0.2b	73.4	1.2	0.0	74.8
<i>Mean</i>	<i>1.8</i>	<i>64.1a</i>	<i>1.3a</i>	<i>0.0</i>	<i>66.7a</i>
ET Cover					
East Subplot	0.9	58.0	0.8	0.0	59.7
West Subplot	3.5	40.4	0.7	0.0	44.6
<i>Mean</i>	<i>2.2</i>	<i>49.2a</i>	<i>0.8ab</i>	<i>0.0</i>	<i>52.1a</i>
<i>Mean East Subplot</i>	<i>1.5</i>	<i>40.6</i>	<i>0.7</i>	<i>0.0</i>	<i>42.8</i>
<i>Mean West Subplot</i>	<i>1.2</i>	<i>41.2</i>	<i>0.6</i>	<i>0.0</i>	<i>43.0</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 9. The mean percent vegetation cover and total percent cover for landfill plot/treatments collected fall of 2000.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
----- percent cover -----					
Phase I					
RCRA Subtitle D					
East Subplot	3.76	0.55	0.34	0.61	5.26
West Subplot	3.50	0.02	0.39	1.10	5.26
<i>Mean</i>	3.63	0.29	0.37	0.86	5.26
GCL					
East Subplot	4.25	0.00	1.69	0.00	5.94
West Subplot	1.05	0.67	1.52	0.00	3.24
<i>Mean</i>	2.65	0.34	1.61	0.00	4.59
RCRA Subtitle C					
East Subplot	4.90	0.80	1.87	0.65	8.22
West Subplot	5.28	1.90	2.19	0.00	9.37
<i>Mean</i>	5.09	1.35	2.03	0.33	8.80
<i>Mean East Subplot</i>	4.30	0.45	1.30	0.42	6.47
<i>Mean West Subplot</i>	3.28	0.86	1.37	0.37	5.96
Phase II					
Capillary Barrier					
East Subplot	0.30	8.47	0.48	0.00	9.25
West Subplot	0.11	0.85	0.47	0.00	1.43
<i>Mean</i>	0.21	4.66	0.48	0.00	5.34
Anisotropic Barrier					
East Subplot	8.50	5.05	1.80	0.00	15.35
West Subplot	0.00	4.75	1.99	0.00	6.74
<i>Mean</i>	4.25	4.90	1.90	0.00	11.05
ET Cover					
East Subplot	4.15	17.15	0.00	0.00	21.30
West Subplot	3.90	7.80	0.35	0.15	12.20
<i>Mean</i>	4.03	12.48	0.18	0.08	16.75
<i>Mean East Subplot</i>	4.32	10.22	0.76	0.00	15.30
<i>Mean West Subplot</i>	1.34	4.47	0.94	0.05	6.79

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 10. The mean species density and total plant density for landfill plot/treatments collected fall of 2000.

Landfill Plot/Treatment	Vegetation Type				
	grass	weed	forbs	shrub	total
----- plant density per 50 x 100 cm plot -----					
Phase I					
RCRA Subtitle D					
East Subplot	4.75	0.25	26.75	0.17	31.92
West Subplot	4.50	0.42	26.08	0.33	31.33
<i>Mean</i>	4.63	0.33	26.42	0.25	31.62
GCL					
East Subplot	8.17	0.58	97.08	0.08	105.92
West Subplot	2.67	3.17	64.00	0.00	69.83
<i>Mean</i>	5.42	1.88	80.54	0.04	87.87
RCRA Subtitle C					
East Subplot	15.42	1.83	63.00	0.75	81.00
West Subplot	9.17	3.42	127.08	0.08	139.75
<i>Mean</i>	12.29	2.63	95.04	0.42	110.37
<i>Mean East Subplot</i>	7.44	1.61	67.33	0.24	76.62
<i>Mean West Subplot</i>	5.44	2.33	72.39	0.14	80.31
Phase II					
Capillary Barrier					
East Subplot	1.33	4.92	13.42	0.00	19.67
West Subplot	3.33	5.83	13.83	0.00	23.00
<i>Mean</i>	2.33	5.38	13.63	0.00	21.33
Anisotropic Barrier					
East Subplot	7.92	10.08	157.58	0.00	175.58
West Subplot	0.08	27.83	141.83	0.00	169.75
<i>Mean</i>	4.00	18.96	149.71	0.00	172.67
ET Cover					
East Subplot	1.67	17.75	1.17	0.00	20.58
West Subplot	1.75	27.25	5.08	0.00	34.08
<i>Mean</i>	1.71	22.50	3.13	0.00	27.33
<i>Mean East Subplot</i>	2.68	15.61	55.49	0.00	73.78
<i>Mean West Subplot</i>	1.72	20.31	53.58	0.00	75.61

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

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Table 11. The influence of wets versus east subplots after seeding on annual biomass in the fall of 1999.

Landfill Type	Treatment		
	East Subplot	West Subplot	Average
	----- gms/m ² -----		
Phase I			
RCRA Subtitle D	121.5	91.7	106.6
GCL	228.3a ¹	91.3b	159.8
RCRA Subtitle C	159.6	119.7	139.6
<i>Mean Phase I</i>	<i>169.8a</i>	<i>100.9b</i>	<i>135.3</i>
Phase II			
Capillary Barrier	79.3a	43.2b	61.3b ²
Anisotropic Barrier	60.5b	68.4a	64.5b
ET Cover	174.5b	210.8a	192.6a
<i>Mean Phase II</i>	<i>104.8</i>	<i>107.5</i>	<i>106.1</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Table 12. The annual biomass for landfill types collected fall of 2000.

Landfill Type	Treatment		
	East Subplot	West Subplot	Average
	----- gms/m ² -----		
Phase I			
RCRA Subtitle D	116.5	62.2	89.4
GCL	181.2	36.6	108.9
RCRA Subtitle C	132.2	109.6	120.9
<i>Mean Phase I</i>	<i>143.3</i>	<i>69.5</i>	<i>106.4</i>
Phase II			
Capillary Barrier	97.1	5.1	51.1
Anisotropic Barrier	117.2	26.2	71.7
ET Cover	280.8	159.0	219.9
<i>Mean Phase II</i>	<i>165.0</i>	<i>63.4</i>	<i>114.2</i>

¹ Different small case letters indicate significant differences (P<0.05) within treatments.

² Different small case italic letters indicate significant differences (P<0.05) between treatments.

Conclusion

Cover profile differences and location within the areas of the plots (e.g., side and toe of plots) contributed directly to vegetation variances. Cover, density, and biomass between Phase I landfill treatments and II were significantly different. The seeded grasses and shrubs were better established on Phase I treatments than Phase II treatments during the first two years but Phase II caught up during the third year. It is believed that this was a result of several things with the major difference being amount of precipitation following construction of the two phases. Precipitation directly affected the interacting factors of soil moisture conditions and the growth season of seeded plants. The seed mixture consisted of cool and warm weather plants. The warm season plants germinate and establish best when seeded early in the growing season. Also, the soil moisture conditions were much more conducive to seed germination and growth during the Phase I construction wet spring conditions than during the dryer Phase II construction summer conditions.

Vegetative cover consisted primarily of native grasses; while weeds occurred in greater number during the first sampling periods and trailed off during the later sampling periods. The native sand dropseed and lesser amounts of sideoats grama and galleta dominated Phase I landfills at each sampling period although the native shrub, fourwing saltbush, and native forbs, hoary aster, were widely scattered over the landfills. Invader species such as annual weeds, fireweed and Russian thistle, were a larger percentage of the vegetative cover and density on Phase II landfills than Phase I throughout the study. The native perennial vegetation would be expected to provide more inherent site stability (i.e. less erosion) than the annual plant vegetation that is easily removed in the spring. The slightly greater biomass production on Phase I compared to Phase II landfills also tends to support similar though less apparent conclusions.

Vegetative cover and plant vigor appeared to increase towards the toe of all landfills, a response to increased soil moisture from up slope runoff (5% slope from center of landfill). Pedicilate perennial plants were observed up slope on all Phase I landfills and an accumulation of fine soil particles were observed at the toe of all landfills, except the ET Cover (cobble mulch) treatment, indicating some surface erosion has occurred on all landfills except the cobble mulch treatment.

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Appendix A

The Landfill Cover Vegetation Information for Years 1997-2000.

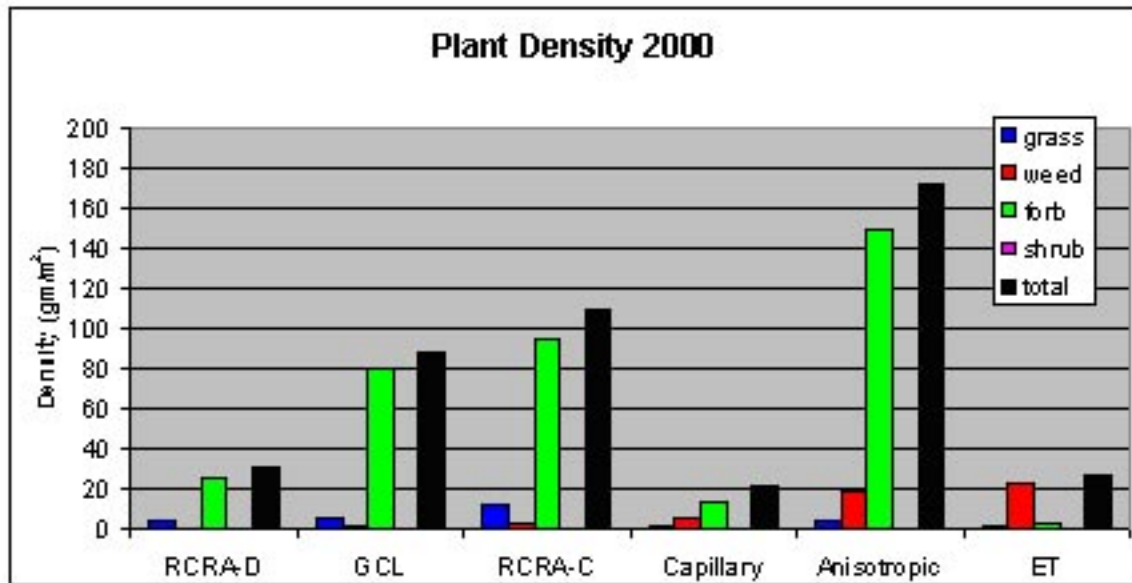


Figure A-1. Plant Density 2000

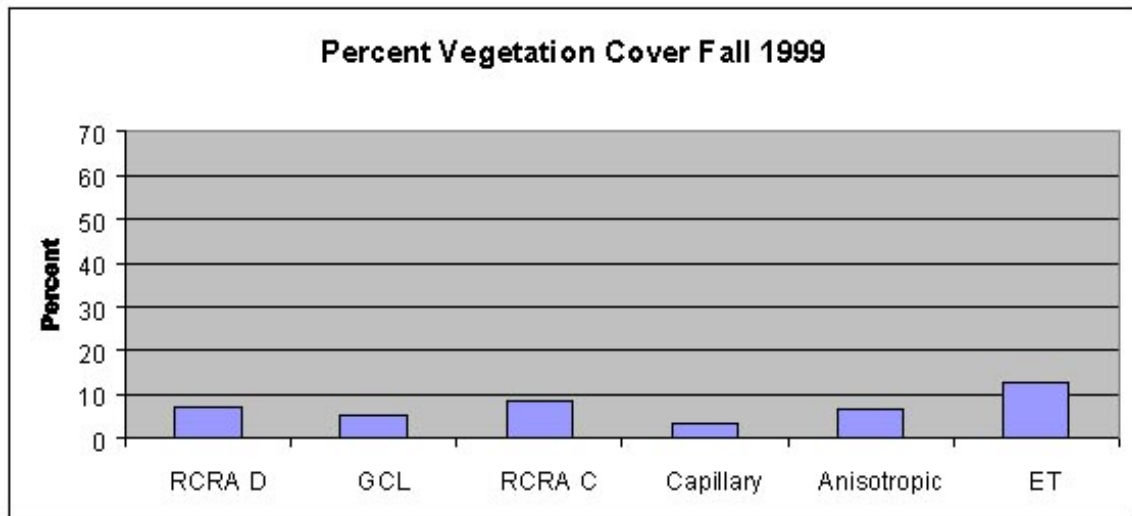


Figure A-2. Percent Vegetation Cover Fall 1999

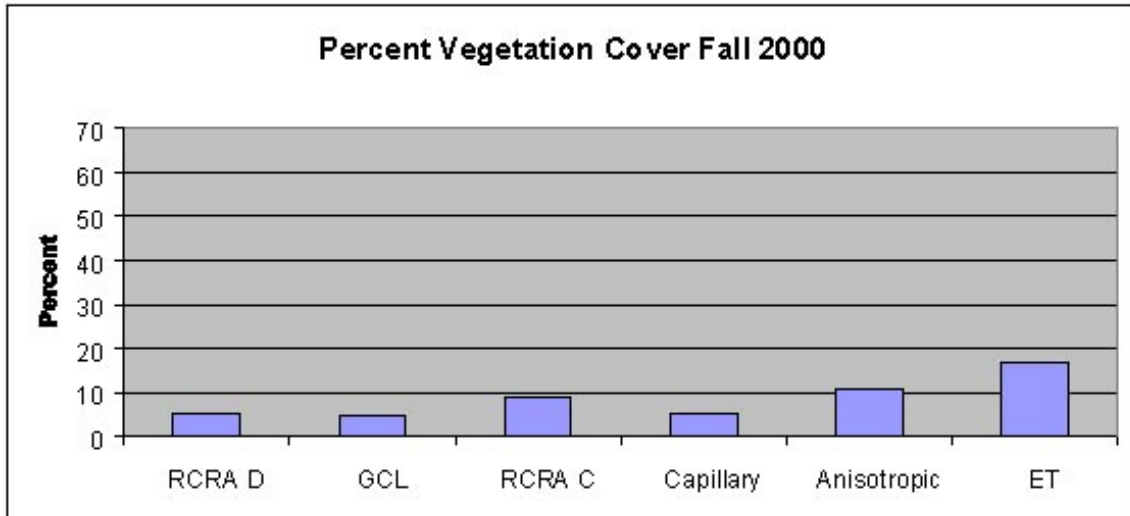


Figure A-3. Percent Vegetation Cover Fall 2000

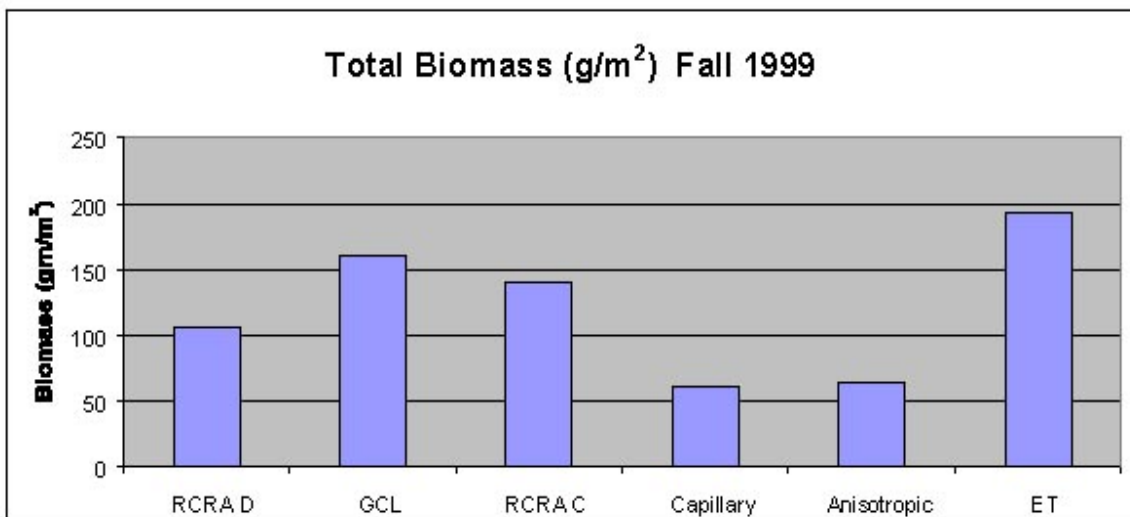


Figure A-4. Total Biomass Fall 1999

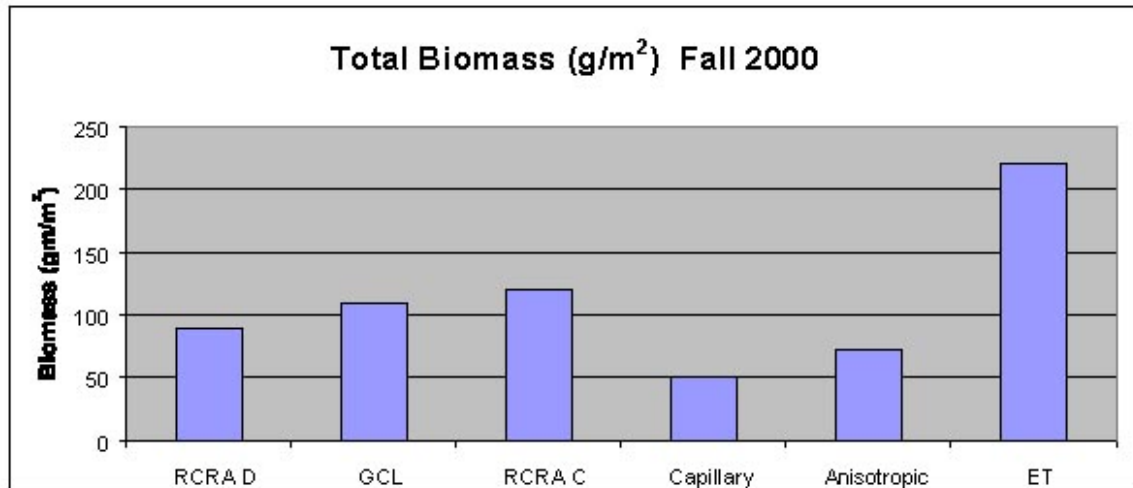


Figure A-5. Total Biomass Fall 2000

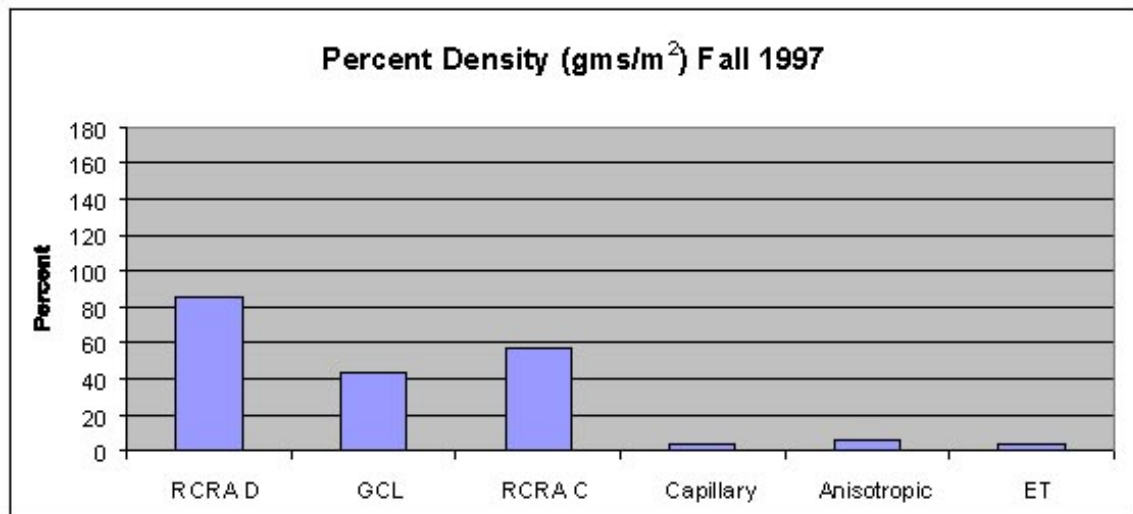


Figure A-6. Percent Density Fall 1997

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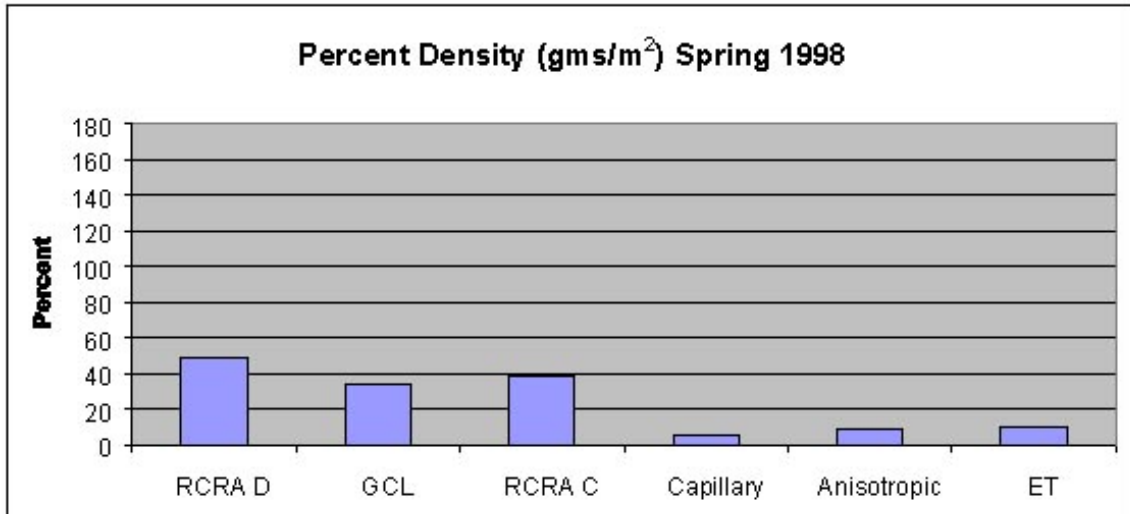


Figure A-7. Percent Density Spring 1998

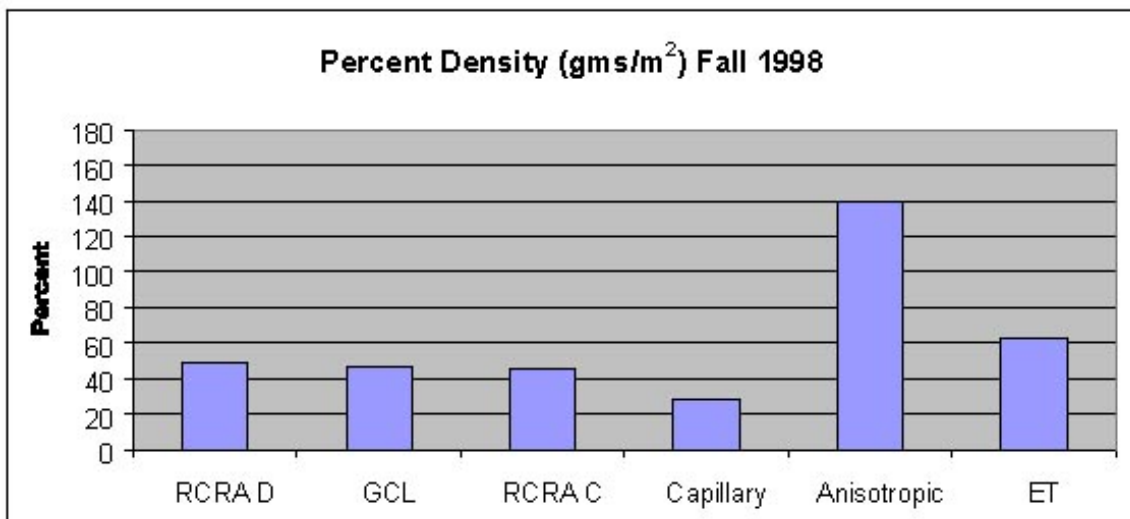


Figure A-8. Percent Density Fall 1998

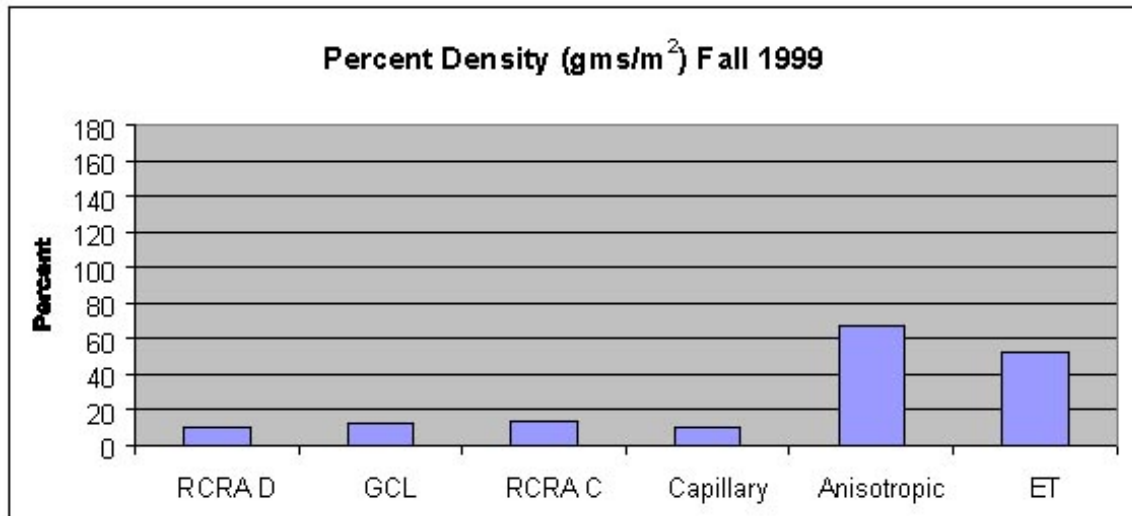


Figure A-9. Percent Density Fall 1999

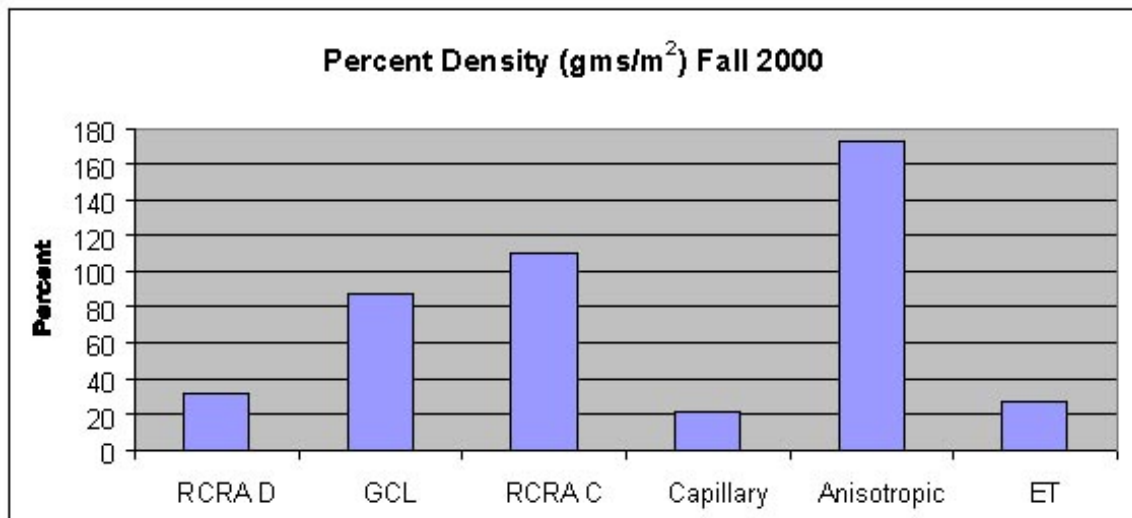


Figure A-10. Percent Density Fall 2000

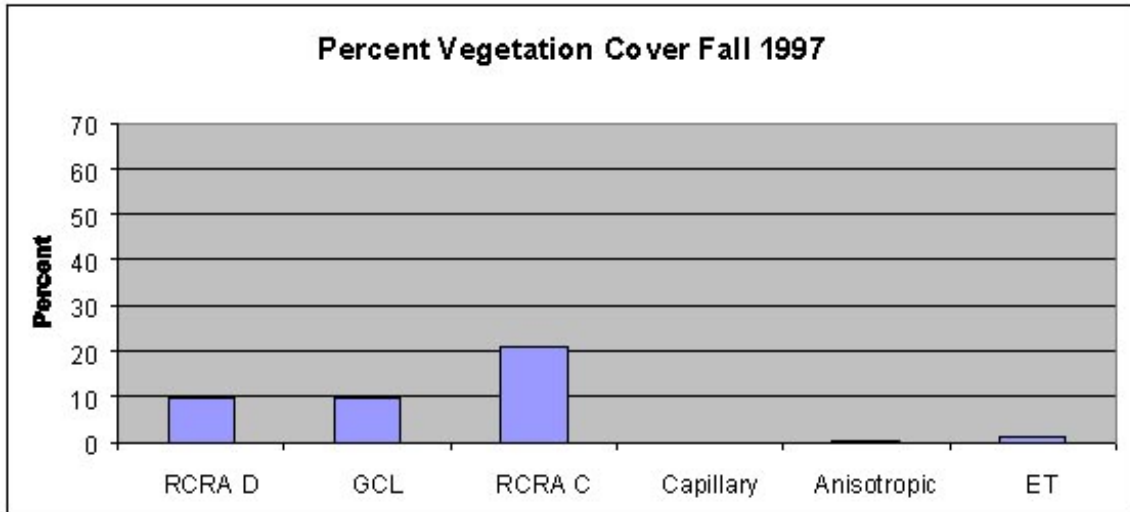


Figure A-11. Percent Vegetation Cover Fall 1997

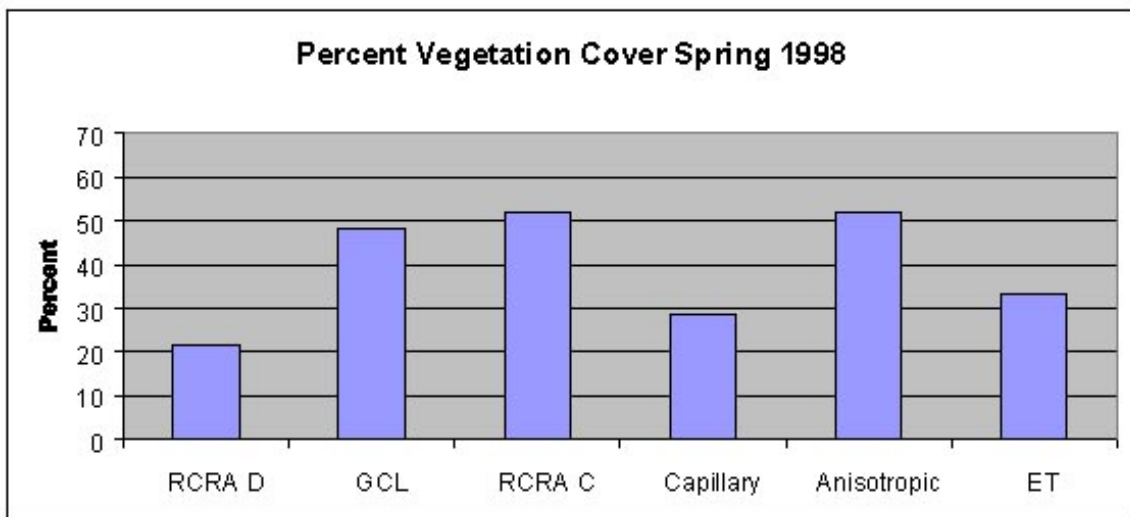


Figure A-12. Percent Vegetation Cover Spring 1998

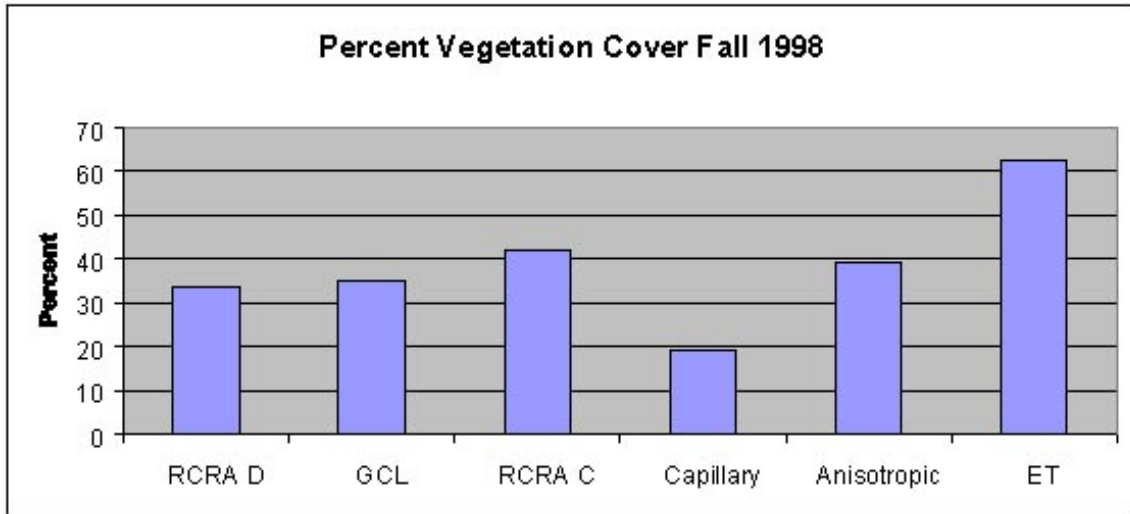


Figure A-13. Percent Vegetation Cover Fall 1998

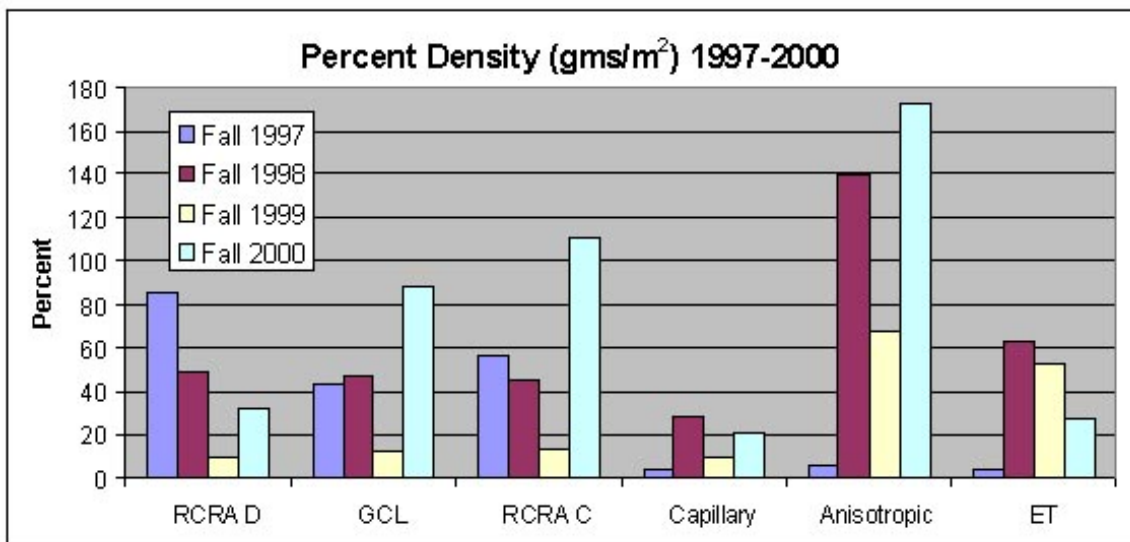


Figure A-13. Percent Density 1997-2000